MOTION STUDY AND WORK DESIGN

Fall 2023

BASIC MOTION ELEMENTS AND WORK ANALYSIS

- ***Motion study*** involves the analysis of the basic hand, arm, and body movements of workers as they perform work.
- ***Work design*** involves the methods and motions used to perform a task. This design includes the workplace layout and environment as well as the tooling and equipment (e.g., workholders, fixtures, hand tools, portable power tools, and machine tools).
- Frank Gilbreth was the first to catalog the basic motion elements. He called each motion a ***therblig*** (Gilbreth spelled backward except for the "th"). Therbligs are the basic building blocks of virtually all manual work performed at a single workplace and consisting primarily of hand motions. Therbligs are relatively few in number, but they are performed over and over, often in very similar sequences, during a given task.
- Therbligs include mental elements as well as physical elements.

Work Analysis Using Therbligs

- Each therblig represents time and energy expended by a worker to perform a task. If the task is repetitive, of relatively short duration, and will be performed many times, it may be appropriate to analyze the therbligs that make up the work cycle as part of the work design process.
- The term ***micromotion analysis*** is sometimes used for this type of analysis. For example, the activities of the right and left hands when performing a manual task can be specified in terms of therbligs. Figure 1 illustrates this kind of analysis for the same task that is described in the right-hand/left-hand activity chart.

Work Analysis Using Therbligs

- The following general objectives are involved in micromotion analysis:

1. Eliminate therbligs that are ineffective if possible; for example, eliminate the need to search for parts or tools by positioning them in a known and fixed location in the workplace.
2. Avoid the use of a hand for holding parts; use a work holder instead.
3. Combinetherbligswherepossible;forexample,performright-handandleft-hand motions simultaneously.
4. Simplifytheoverallmethod;forexample,resequencetherbligsinthecycle.
5. Reduce the time required for the motion; for example, shorten distances of therbligs such as transport empty and transport loaded.

TABLE 1 Gilbreth's Seventeen Therbligs

Therblig	Letter Symbol	Description
Transport empty	TE	Reaching for an object with empty hand; for example, reach for a part prior to grasping and moving the part. Today, we commonly refer to the transport empty motion element as a "reach."
Grasp	G	Grasping an object by contacting and closing the fingers of the active hand about the object until control has been achieved.
Transport loaded	TL	Moving an object using a hand motion; for example, moving a part from one location to another at a workstation. Today, we commonly refer to a transport loaded motion element as a "move."
Hold	H	Holding an object; for example, holding an object with one hand while the other hand performs some operation on it.
Release load	RL	Releasing control of an object, typically by opening the fingers that held it and breaking contact with the object.
Preposition	PP	Positioning and/or orienting an object for the next operation and relative to an approximate location; for example, lining up a pin next to a hole for insertion into the hole. Preposition usually follows transport loaded.
Position	P	Positioning and/or orienting an object in the defined location that is intended for it. Position is generally performed during transport loaded; for example, moving a pin toward a hole and simultaneously lining it up in preparation for insertion into the hole.
Use	U	Manipulating and/or applying a tool in the intended way during the course of working, usually on an object; for example, using a screwdriver to turn a threaded fastener or using a pen to sign one's name.
Assemble	A	Joining two parts together to form an assembled entity; for example, using a threaded fastener to assemble two mating parts by hand.
Disassemble	DA	Separating multiple components that were previously joined in some way; for example, unfastening two parts held together by a threaded fastener.
Search	Sh	Attempting to find an object using the eyes or hand, concluding when the object is found.
Select	St	Choosing among several objects in a group, usually involving hand-eye coordination, and concluding when the hand has located the selected object.
Plan	Pn	Deciding on a course of action, usually consisting of short pause or hesitation in the motions of the hands and/or body.
Inspect	I	Determining the quality or characteristics of an object using the eyes and/or other senses.
Unavoidable delay	UD	Waiting due to factors beyond the control of the worker and included in the work cycle; for example, waiting for a machine to complete its feed motion.
Avoidable delay	AD	Waiting that is within the worker's control, causing idleness that is not included in the regular work cycle; for example, the worker opening a pack of chewing gum.
Rest	R	Resting to overcome fatigue, consisting of a pause in the motions of the hands and/or body during the work cycle or between cycles.

TABLE 3 Micromotion Analysis Checklist for Possible Improvements

Therblig	Questions and Suggestions
Transport empty (TE)	Minimize number of parts in the product to reduce frequency of TE and TL. Minimize reach distance required. Use parts bins that have easy access. Can abrupt changes in direction of movement of body member be eliminated or minimized? Locate parts and tools used most frequently near their respective points of use. Minimize requirements for hand-eye coordination during reach. Can right and left hands be used simultaneously to accomplish two transport empty motions?
Grasp (G)	Use parts bins that have easy access. Use workholders that have fast release mechanism. For example, screw type vises are time consuming to operate, while pneumatic clamps are fast-acting. Locate parts and tools in known locations to save time in searching. Can right and left hands be used simultaneously to accomplish two grasp motions? Avoid transfer of objects from one hand to the other. Design parts that do not tangle.
Transport loaded (TL)	Can parts be slid across work surface rather than carried above work surface? This usually saves time. Can abrupt changes in direction of movement of body member be eliminated or minimized? Design parts and tools to be as lightweight as possible to save move time. Minimize number of parts in the product to reduce frequency of TE and TL. Minimize move distance required. Locate parts and tools used most frequently near their respective points of use. Minimize requirements for hand-eye coordination during movement. Can right and left hands be used simultaneously to accomplish two transport loaded motions?
Hold (H)	This is considered an ineffective therblig. Can it be eliminated? Can a workholding device (e.g., fixture, jig, vise, clamp) be used instead of holding by hand? Can friction, an adhesive, or a mechanical stop be used instead of holding by hand? If holding by hand cannot be eliminated, can an armrest be provided?
Release load (RL)	Is it possible to release the object by dropping it (e.g., into a chute)? Is the delivery point (e.g., bin, workholder) designed for ease of release of the object? Minimize requirements for hand-eye coordination during release.
Preposition (PP)	This is considered an ineffective therblig. Can it be eliminated? Can symmetry of prepositioning be increased? For example, it is easier to preposition a round shaft relative to a round hole than a square shaft relative to a square hole because of increased symmetry of the fit. Can a guide be designed to facilitate prepositioning? Can an armrest be used to steady the hand during prepositioning? Design parts and tools to be as lightweight as possible to save prepositioning time. Make sure object is grasped properly to facilitate prepositioning.
Position (P)	This is considered an ineffective therblig. Can it be eliminated? Can symmetry of positioning be increased? For example, it is easier to position a round shaft relative to a round hole than a square shaft relative to a square hole because of increased symmetry of the fit. Can a guide be designed to facilitate positioning? Can an armrest be used to steady the hand during positioning? Can tools be suspended from overhead to avoid positioning? Design parts and tools to be as lightweight as possible to save positioning time. Make sure object is grasped properly to facilitate positioning.
Use (U)	Can a more efficient hand tool be designed to reduce the time of the use motion? Can a portable power tool be devised to reduce the time of the use motion?

Dr. Shahd Obeidat

Therblig	Questions and Suggestions
	The part should be held in a workholder during the use motion. Can a jig be designed to guide the use of the tool? A ***jig*** is a special workholder that has a mechanism for guiding the tool. Can a mechanized or automated operation be used to eliminate the need for the use motion?
Assemble (A)	Can a hand tool be designed to reduce the time required for the assembly motion? Can a portable power tool be devised to reduce the time of the assembly motion? The base part or existing subassembly should be positioned in a workholder during the assembly motion. Can the product be designed with fewer components to minimize assembly time? Design the product for automated assembly to eliminate the need for manual assembly.
Disassemble (DA)	Can a hand tool be designed to reduce the time required for the disassembly motion? Can a portable power tool be devised to reduce the time required for the disassembly motion? The base part or existing subassembly should be positioned in a workholder during the disassembly motion.
Search (Sh)	This is considered an ineffective therblig. Can it be eliminated? Make sure lighting is adequate to facilitate searching. Can parts be fed from magazines or chutes to avoid searching? Locate tools in known positions in the workplace to facilitate searching; for example, suspend tools from overhead. Can different parts be made with different colors to facilitate searching?
Select (St)	This is considered an ineffective therblig. Can it be eliminated? Use parts bins that have easy access. Make sure lighting is adequate to facilitate selecting. Can parts be fed from magazines or chutes for one-at-a-time selection? Can different parts be made with different colors to facilitate searching?
Plan (Pn)	This is considered an ineffective therblig. Can it be eliminated? Remove the need for the worker to decide on a course of action that causes hesitation in the work cycle.
Inspect (I)	Make sure lighting is adequate to facilitate the inspection procedure. Minimize the number of characteristics to inspect. Only the key characteristics of the part should be inspected. Time should not be wasted inspecting unimportant characteristics. Can the object be inspected using gauges instead of actually measuring the characteristics of interest? Gauging takes less time than measuring. Can inspection be combined with another operation so it is not performed separately? Can inspection be automated (e.g., machine vision) to eliminate the need for a worker to accomplish it (e.g., visually)? Can multiple but separate inspection steps be combined into one inspection?
Unavoidable delay (UD)	This is considered an ineffective therblig. Can it be eliminated? Eliminate the reason for the delay. For example, can the machine speed be increased to reduce the machine cycle time? Can external work elements be made into internal work elements to fill up the delay time with useful work activities?
Avoidable delay (AD)	This is considered an ineffective therblig. Can it be eliminated? Eliminate the reason for the delay. Provide incentives for the worker to minimize delay time.
Rest (R)	Reduce metabolic load on worker through the use of machines and tools to minimize need for rest breaks. Improvements in methods and motions through analysis of previous therbligs should reduce need for rest breaks.

PRINCIPLES OF MOTION ECONOMY AND WORK DESIGN

- The principles of motion economy can be organized into three categories: (1) principles related to the use of the human body, (2) principles related to workplace arrangement, and (3) principles related to the design of tooling and equipment.

- They are guidelines that can be used to help determine the work method, workplace layout, tools, and equipment that will maximize the efficiency and minimize the fatigue of the worker.

Principles Related to the Use of the Human Body

- They are most applicable to manual work, either repetitive or nonrepetitive.

1. ***Both hands should be fully utilized.*** The natural tendency of most people is to use their preferred hand to accomplish most of the work. Both hands should be used as equally as possible (holding is not counted).

2. ***The two hands should begin and end their motions at the same time.*** **T**he work is evenly divided between the right-hand side and the left-hand side of the workplace. In this case, the division of work should be organized according to the following principle.

3. ***The motions of the hands and arms should be symmetrical and simultaneous***. This will minimize the amount of hand-eye coordination required by the worker. If this is the case, then the principle that follows next is applicable.

Principles Related to the Use of the Human Body

- They are most applicable to manual work, either repetitive or nonrepetitive.

4. ***The work should be designed to emphasize the worker's preferred hand***. The preferred hand is faster, stronger, and more dexterous. If the work to be done cannot be allocated evenly between the two hands, then the method should take advantage of the worker's best hand. For example, work units should enter the workplace on the side of the worker's preferred hand and exit the workplace on the opposite side. The reason is that greater hand-eye coordination is required to initially acquire the work unit, so the worker should use the preferred hand for this element. Releasing the work unit at the end of the cycle requires less coordination.

5. ***The worker's two hands should never be idle at the same time***. The work cycle of a worker-machine system may be an exception, if the worker is responsible for monitoring the machine during its automatic cycle, and monitoring involves using the worker's cognitive senses rather than the hands. If machine monitoring is not required, then internal work elements should be assigned to the worker during the automatic cycle.

Case Study

- Barnes [4] cites the results of a study done at the University of Iowa in which a right-handed worker performed a relatively simple manual task consisting of reaching, selecting, grasping, transporting, and releasing small parts. The task was accomplished using two different containers for the parts: a rectangular bin and a bin with tray (the bin with tray making it easier to perform the select and grasp elements). The worker performed the work cycle with each container using (1) only the right hand, (2) only the left hand, and (3) both hands performing symmetrical and simultaneous motions.
- As expected, the right-handed worker was able to complete the work cycle in the shortest time using the right hand. Also as expected, the work cycle using both hands took the longest time. However, two parts were completed using both hands, so the time per part for each tray type is one-half the value shown. Accordingly, using both hands was the most productive method.

TABLE 4 Study Results of a Task Performed One-Handed and Two-Handed

	Rectangular Bin			Bin with Tray		
	Right Hand	Left Hand	Both Hands	Right Hand	Left Hand	Both Hands
Time to perform	1.04 sec	1.10 sec	1.48 sec	0.81 sec	0.91 sec	1.07 sec
Normalized time	100%	106%	142%	100%	112%	132%

Principles Related to the Use of the Human Body

- The next five principles of motion economy attempt to utilize the laws of physics to assist in the use of the hands and arms while working.

6. ***The method should consist of smooth continuous curved motions rather than straight-line motions with abrupt changes in direction.*** The reason behind this principle is that the straight-line path sequence includes start and stop actions (accelerations and decelerations) that consume the worker's time and energy. Motions consisting of smooth continuous curves minimize the lost time in starts and stops.

7. ***Momentum should be used to facilitate the task wherever possible.*** When carpenters strike a nail with a hammer, they are using *momentum*, which can be defined as mass times velocity. Imagine trying to apply a static force to press the nail into the wood. Not all work situations provide an opportunity to use momentum as a carpenter uses a hammer, but if the opportunity is present, exploit it. The previous principle dealing with smooth continuous curved motions illustrates a beneficial use of momentum (i.e., conservation of momentum) to make a task easier.

Principles Related to the Use of the Human Body

6. ***The method should take advantage of gravity instead of opposing it.*** Less time and energy are required to move a heavy object from a higher elevation to a lower elevation than to move the object upward.
7. ***The method should achieve a natural rhythm of the motions involved.*** Rhythm refers to motions that have a regular recurrence and flow from one to the next. Basically, the worker learns the rhythm and performs the motions without thinking, much like the natural and instinctive motion pattern that occurs in walking.
8. ***The lowest classification of hand and arm motions should be used.*** The five classifications of hand and arm motions are presented in Table 5. With each lower classification, the worker can perform the hand and arm motion more quickly and with less effort. Therefore, the work method should be composed of motions at the lowest classification level possible. This can often be accomplished by locating parts and tools as close together as possible in the workplace.

Principles Related to the Use of the Human Body

TABLE 5 Five Classifications of Hand and Arm Motions

Classification	Defined as:
1	Finger motions only
2	Finger and wrist motions
3	Finger, wrist, and forearm motions
4	Finger, wrist, forearm, and upper arm motions
5	Finger, wrist, forearm, upper arm, and shoulder motions

Principles Related to the Use of the Human Body

- The two remaining human body principles of motion economy are recommendations for using body members other than the hands and arms.

11. ***Minimize eye focus and eye travel activities.*** In work situations where hand-eye coordination is required, the eyes are used to direct the actions of the hands. *Eye focus* occurs when the eye must adjust to a change in viewing distance. for example, from 25 in. to 10 in. with little or no change in line of sight. *Eye travel* occurs when the eye must adjust to a line-of-sight change. for example, from one location in the workplace to another, but the distances from the eyes are the same. Since eye focus and eye travel each take time, it is desirable to minimize the need for the worker to make these adjustments as much as possible. This can be accomplished by minimizing the distances between objects (e.g., parts and tools) that are used in the workplace.

12. ***The method should be designed to utilize the worker's feet and legs when appropriate.*** The legs are stronger than the arms, although the feet are not as dexterous as the hands. The work method can sometimes be designed to take advantage of the greater strength of the legs, for example, in lifting tasks.

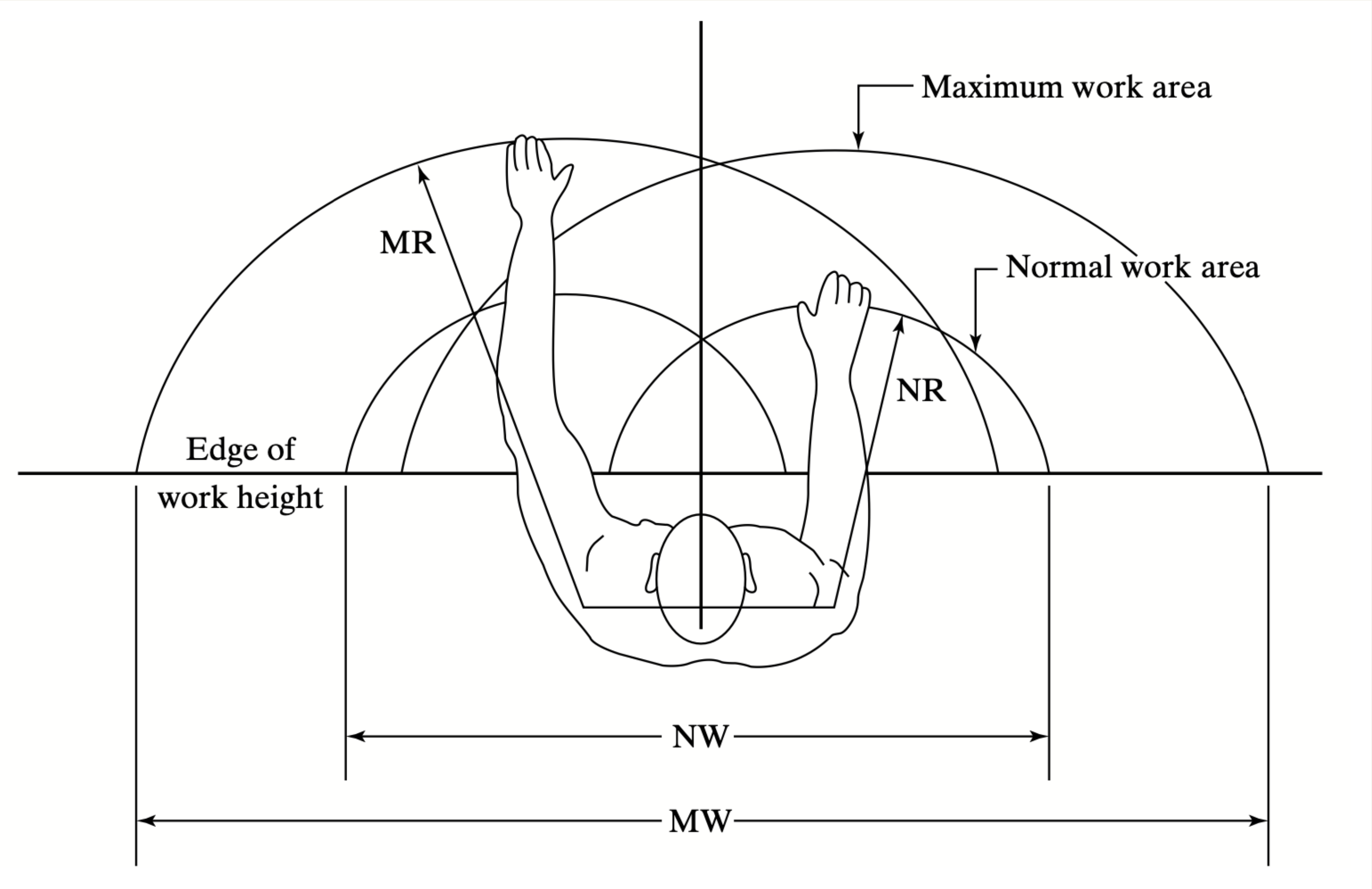
Principles Related to Workplace Arrangement

- The first three principles deal with the immediate work area and contribute to a natural rhythm in the work cycle. The other principles cover the use of gravity and the general conditions of the workplace.

1. ***Tools and materials should be located in fixed positions within the work area.*** As the saying goes, "a place for everything, and everything in its place." The worker eventually learns the fixed locations, allowing him or her to reach for the object without wasting time looking and searching.
2. ***Tools and materials should be located close to where they are used.*** This helps to minimize the distances the worker must move (travel empty and travel loaded) in the workplace. In addition, any equipment controls should also be located in close proximity. This guideline usually refers to a normal and maximum working area, as shown in Figure 2 and clarified further in Table 6. It is generally desirable to keep the parts and tools used in the work method within the normal working area, as defined for each hand and both hands working together. If the method requires the worker to move beyond the maximum working area, then the worker must move more than just the arms and hands. This expends additional energy, takes more time, and ultimately contributes to greater worker fatigue.

Principles Related to Workplace Arrangement

- Normal and maximum working areas in the workplace. See Table 6 for working area dimensions of average male and female workers.



Principles Related to Workplace Arrangement

TABLE 6 Normal and Maximum Working Area Dimensions in Figure 2

Symbol in Figure 2	Dimension in Working Area for Worker Seated at Worktable	Male Worker [cm (in)]	Female Worker [cm (in)]
NR	Normal radius of arm reach	39 (15.5)	36 (14.0)
MR	Maximum radius of arm reach	67 (26.5)	60 (23.5)
NW	Normal width of arm reach	109 (43.0)	102 (40.0)
MW	Maximum width of arm reach	163 (64.0)	147 (58.0)

Principles Related to Workplace Arrangement

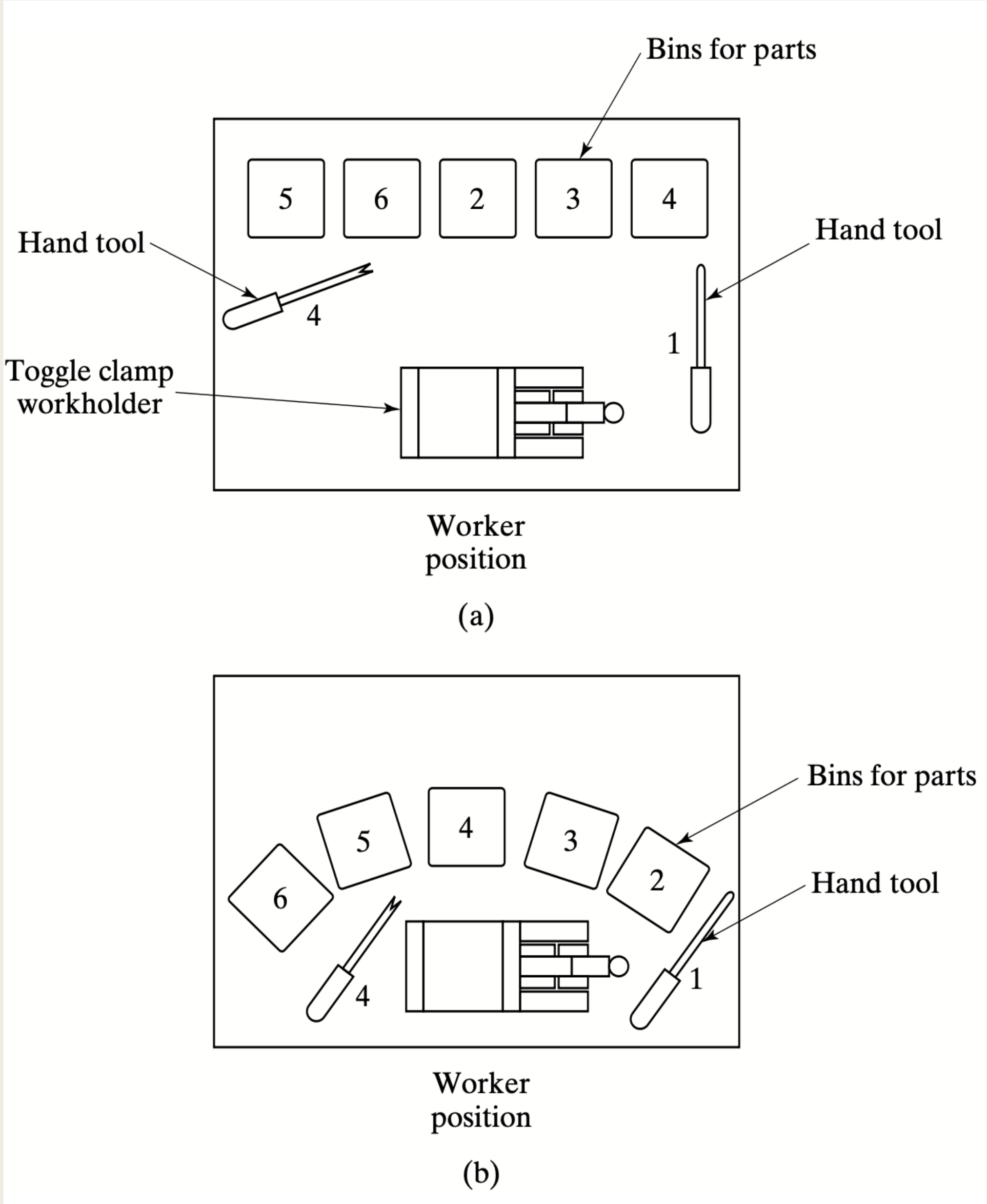
3. Tools and materials should be placed in locations that are consistent with the sequence of work elements in the work cycle. Items should be arranged in a logical pattern that matches the sequence of work elements. Those items that are used first in the cycle should be on one side of the work area, the items used next should be next to the first, and so on, until the last items are obtained on the other side of the work area. The alternative to this sequential arrangement is to locate items randomly about the work area. This increases the amount of searching required and detracts from the rhythm of the work cycle.

4. Gravity feed bins should be used to deliver small parts and fasteners. A gravity feed bin is a container that uses gravity to move the items in it to a convenient access point for the worker. One possible design is shown in Figure 4(a). It generally allows for quicker acquisition of an item than a conventional rectangular tray shown in Figure 4(b).

5. ***Gravity drop chutes should be used for completed work units where appropriate***. The drop chutes should lead to a container adjacent to the worktable. The entrance to the gravity chute should be located near the normal work area, permitting the worker to dispose of the finished work unit quickly and conveniently. There are obvious limitations on the use of gravity chutes. They are most appropriate for lightweight work units that are not fragile.

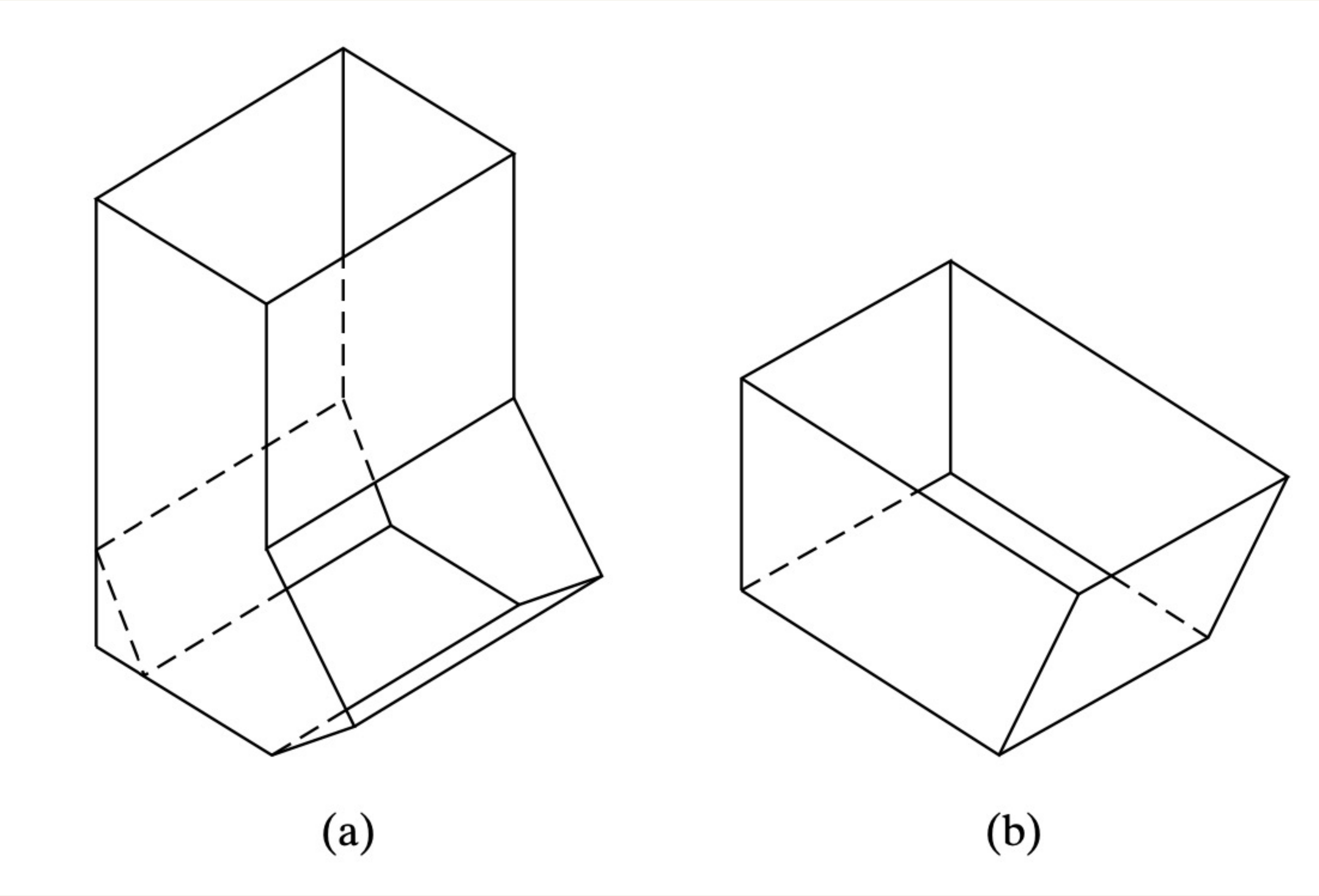
Principles Related to Workplace Arrangement

- Figure 3 shows the top view of a workplace layout that illustrates these first three principles. Note that the layout in (b) locates bins in a more accessible pattern that is consistent with the sequence of work elements. Two workplace layouts. The layout in (b) illustrates principles of good workplace arrangement while the one in (a) does not. Numbers indicate sequence of work elements in relation to locations of hand tools and parts bins.



Principles Related to Workplace Arrangement

- Two types of bins used for small parts and fasteners in the workplace: (a) gravity feed bin and (b) conventional rectangular bin.



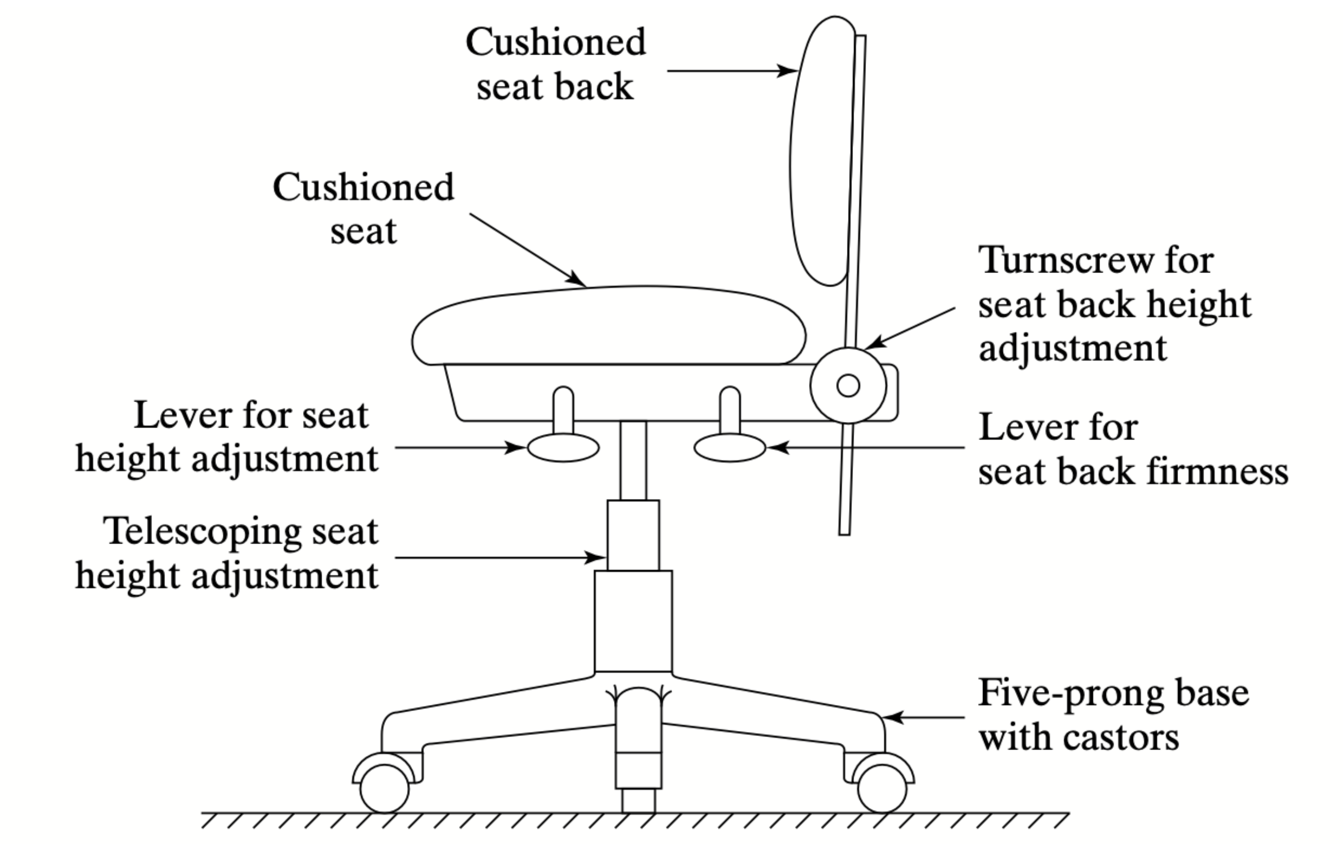
Principles Related to Workplace Arrangement

6. ***Adequate illumination must be provided for the workplace.*** The issue of illumination is normally associated with ergonomics. Illumination is especially important in visual inspection tasks. Adequate illumination means not only enough light on the work area; it also refers to color, absence of glare, contrast among items in the field of view, and the location of the light source(s). Noise and temperature are also important.

7. ***A proper chair should be provided for the worker.*** This usually means an adjustable chair that can be fitted to the size of the worker. The adjustments usually include seat height and back height. Both the seat and back are padded. Many adjustable chairs also provide a means of increasing and decreasing the amount of back support. The chair height should be in proper relationship with the work height.

Principles Related to Workplace Arrangement

- An adjustable chair for the workplace. The adjustments provide comfortable seating related to the size of the worker and the work height.



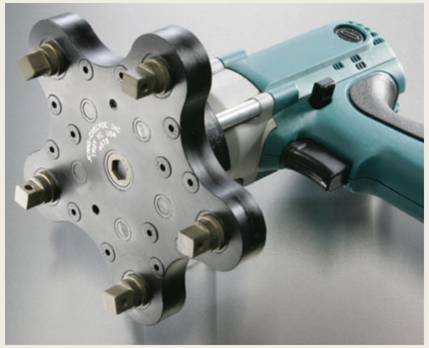
Principles Related to the Design of Tooling and Equipment

1. ***Workholding devices should be designed for the task; a worker's hand should not be used as a workholder***. A mechanical workholder with a fast-acting clamp permits the work unit to be loaded quickly and frees both hands to work on the task productively. Typically, the workholder must be custom-designed for the work part processed in the task. A conventional vise is not recommended for a repetitive work cycle because of its slow-acting screw clamping mechanism.

2. ***The hands should be relieved of work elements that can be performed by the feet***. Foot pedal controls can be provided instead of hand controls to operate certain types of equipment. Sewing machines and church organs are two examples in which foot pedals are used as integral components in the operation of the equipment. As our examples suggest, training is often required for the operator to become proficient in the use of the foot pedals.

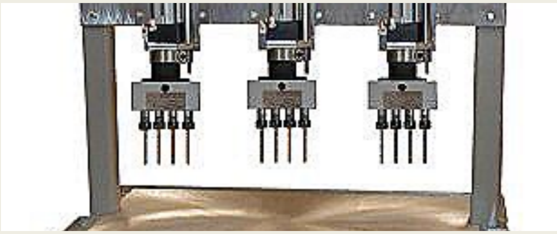
3. ***Multiple tooling functions should be combined into one tool whenever possible***. Many of the common hand tools and implements exhibit this principle. The head of a claw hammer is designed for both striking and pulling nails. Nearly all pencils are designed for both writing and erasing. Less time is usually required to reposition such a double-function tool than to put one tool down and pick another one up.

Principles Related to the Design of Tooling and Equipment



4. *Multiple operations should be performed simultaneously rather than sequentially whenever possible*. A work cycle is usually conceptualized as a sequence of work elements or steps. The steps are performed one after the other by the worker and/or machine. In some cases, the work method can be designed so that the steps are accomplished at the same time rather than sequentially. Special tooling and processes can often be designed to simultaneously accomplish the multiple operations. Examples include the following:

- Pneumatically powered, multiple-spindle lug nut runner used to attach wheels to the car in automobile final assembly plants
- Multiple-spindle drill presses to drill holes in printed circuit boards
- Wave soldering in electronics assembly to solder all connections on a printed circuit board simultaneously.



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Principles Related to the Design of Tooling and Equipment

5. ***Where feasible, an operation should be performed on multiple parts simultaneously***. This usually applies to cases involving the use of a powered tool such as a machine tool. A good example is the drilling of holes in a printed circuit board (PCB). The PCBs are stacked three or four thick, and a numerically controlled drill press drills each hole through the entire stack in one feed motion.

6. ***Equipment controls should be designed for operator convenience and error avoidance.*** Equipment controls include dials, cranks, levers, switches, push buttons, and other devices that regulate the operation of the equipment. All of the controls needed by the operator should be located within easy reach, so as to minimize the body motions required to access and actuate them. In addition, the controls should be designed to be mistake-proof, so that the operator does not cause an equipment action that is different from the one intended.

7. ***Hand tools and portable powered tools should be designed for operator comfort and convenience.*** For example, the tools should have handles or grips that are slightly compressible so that they can be held and used comfortably for the duration of the shift. The location of the handle or grip relative to the working end of the tool should be designed for maximum operator safety, convenience, and utility of the tool. If possible, the tool should accommodate both right-handed and left- handed workers.

Principles Related to the Design of Tooling and Equipment

6. ***Manual operations should be mechanized or automated wherever economically and technologically feasible.*** Mechanized or automated equipment and tooling that are designed for the specific operation will almost always outperform a human worker in terms of speed, repeatability, and accuracy. This results in higher production rates and better quality products. The economic feasibility depends on the quantities to be produced. In general, higher quantities are more likely to justify the investment in mechanization and automation. The techno- logical feasibility relates to the time and difficulty involved in mechanizing or automating a given operation. The time issue is the amount of time required to design and build an automated machine. It may take more than a year before the equipment can be installed, but the company must begin production right away on a product with a short life cycle. The difficulty issue refers to problems such as (1) physical access to the work location, (2) adjustments required in the task, (3) requirements of manual dexterity, and (4) demands on hand-eye coordination.